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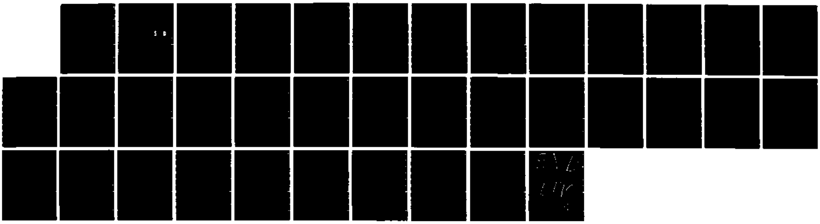

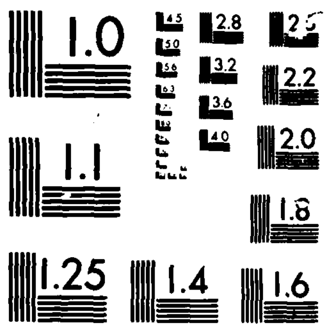

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NRL Memorandum Report 5776

GAMBLE-II Imploding Sodium Plasma
II. Uniformly Filled Z-Pinch

J. Davis, J. E. Rogerson and J. P. Apruzese

Plasma Radiation Branch
Plasma Physics Division

May 8, 1986

This research was sponsored by the Defense Nuclear Agency under Subtask QIEQMXLA, work unit 00006 and work unit title "XRL Source."

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The dynamics and radiative properties of a GAMBLE II imploded uniformly filled sodium Z-pinch plasma are described. Parameters for the initial plasma have been carefully chosen to coincide with current experiments involving a capillary discharge. Results indicate that the sodium heliumlike resonance line achieves sufficiently high radiated flux levels to provide an interesting source of radiation for fluorescence and x-ray laser experiments with a comparison neon plasma.

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CONTENTS

GAMBLE-II IMPLODING SODIUM PLASMA
II. Uniformly Filled Z-Pinch

I. Introduction

The feasibility of developing a source of intense x-ray emission from an imploding sodium gas puff plasma on the GAMBLE II generator in support of x-ray laser experiments has been firmly established theoretically.[1] The results of numerical simulations using the SIMPLODE code to characterize the implosion dynamics of a sodium gas puff plasma indicate that it is theoretically feasible to generate significant radiation flux levels in the heliumlike resonance line for the flashlamp x-ray laser concept to succeed. Preliminary calculations support the possibility of observing fluorescence in the heliumlike neon system for the sodium flux levels achievable by the GAMBLE II generator and possibly lasing when the higher power DOUBLE EAGLE generator drives the sodium plasma and creates the flashlamp. Unfortunately, sodium as a material load introduces a variety of experimental problems that are not easily solved technologically. However, because the Na/Ne x-ray laser scheme is still the prototype of the line coincidence photopumping schemes, it is important to establish its validity experimentally.

However, as already mentioned, making a sodium gas puff plasma is a challenging experimental problem. Rather than "fly in the face of adversity" and try to overcome some of the technological difficulties, an alternative approach will be adopted. The procedure involves using a capillary discharge to create a sodium plasma which is injected between the cathode/anode gap on GAMBLE II. Instead of a hollow annular gas puff plasma, initial experiments with this technique should produce a uniformly filled plasma. The experimental apparatus and procedure are discussed elsewhere by F. C. Young, et. al.[2] The flow dynamics and characteristics of the capillary discharge and injection into the GAMBLE II test area will be presented by D. Mosher in a separate report. We will assume that this procedure is possible and investigate the implosion dynamics of a uniformly filled sodium Z-pinch plasma. As in our earlier investigation, the focus will be on the radiation flux levels achieved in the heliumlike resonance line of sodium.

Manuscript approved February 19, 1986.

II. Results and Discussion

Calculations were performed to evaluate the performance of an imploding Z-pinch sodium plasma for conditions typical of the GAMBLE II generator. The mass per unit length is uniformly distributed and taken to be 30 μgm/cm in all the simulations. The current waveform driving the plasma is shown in Fig. 1 as a function of time and has a peak value of 1.2 Megamps at about 70 nsec. The plasmas' morphology is shown in the subsequent Figs. 2-6 where radius, velocity, temperature, ion density, and total yield are shown as a function of time, respectively. The initial plasma radius was chosen as 0.75 cm. The figures are self-explanatory and do not exhibit any unusual features. Because the plasma is tighter, i.e. a smaller initial radius, the peak plasma parameters occur in time closer to peak current than similar gas puff simulations. At the plasma pinch, the temperature and ion density peak, reaching values of about 1.55 keV and $5\times10^{19}cm^{-3}$, respectively. For such high values of temperature the ionization stages are burned-through, fully stripping the plasma. This result will subsequently manifest itself in a reduction of the line radiation, producing a dip in the radiation profile. The total radiative yield for this case reaches a value of 6.9 Kjoules and reflects good coupling between load and generator, from a radiative viewpoint.

The behavior of the various components of the radiative power (Watts) is presented in Figs. 7-18. These include contributions from bound-bound, free-bound, and free-free processes. In addition, the results are further catalogued into two energy groups - above and below 1 keV. The line radiation is further divided into the L- and K-line contributions. All the results presented in Figs. 7-18 are shown as a function of time. Also, since similar results have been described elsewhere in considerable detail and most of what is presented here is self-explanatory, we will adopt a Cook's tour philosophy and only point out some interesting features along the way. In Fig. 7 the line radiation below 1 keV exhibits a dip in the radiated power just at the time of the pinch. This also coincides with the time of peak temperature reducing the available number of lower charge states from which the bulk of this radiation emanates. In Fig. 8 the very early time behavior should be ignored because it represents the initial conditions, i.e., an initial temperature of 20 eV. The bulk of this

radiation is due to free-bound processes. Figs. 9 and 10 display similar quantities except these represent contributions from transitions above 1 keV. Note the differences in magnitudes between these two sets of figures. In Fig. 11 we have superimposed the L- and K-line contributions while in Fig. 12 the continuum has been included. Figs. 13 and 14 are the same as Figs. 11 and 12 but are linear in Y instead of logarithmic. This provides a more realistic idea of the magnitudes of the various quantities. Also note that on Fig. 13 the K-line peak slightly precedes the L-line peak; this also occurs on some of the gas puff simulations. The final four figures of this set present the total radiated cooling rates for line, continuum (including bremsstrahlung), bremsstrahlung alone, and the sum of all these. They are shown in Figs. 15, 16, 17 and 18, respectively. At peak implosion the bremsstrahlung and free-bound continuum contributions are comparable and are of the same order as the total line contribution. Again, this is a reflection of the high temperature at pinch. The emission spectrum (Watts/cm^2) is shown as a function of energy (keV) at 84.2 nsec into the implosion in Fig. 19. Due to the high temperature at peak implosion the most prominent features of the spectrum are the hydrogen- and helium-like resonance lines, respectively. A few additional transitions are identified for convenience. They are represented as H and He transitions for brevity. Also, some of the lines originate from superlevels or lumped levels and they appear simply as, for example, H(5-2). Finally, over 75% of the total radiated power is due to line radiation and is predominantly from the K-shell. The heliumlike resonance line accounts for about 25% of the total line radiation. The peak radiated power from this line is about 8×10^{10} watts as shown in Fig. 20. The dip in this power profile near peak is explained above. The radiated power from the heliumlike resonance line as a function of radius for a fixed mass of 30μgm/cm and length of 4 cm is shown in Fig. 21. In comparison with the radiated power from a sodium gas puff plasma, the uniformly filled Z-pinch plasma generates a slightly higher radiative flux for smaller initial radius. The more important virtue of the uniformly filled plasma is that it is probably easier to produce experimentally and inject into the diode gap than a hollow annular plasma.

In summary, both the uniformly filled and hollow Z-pinch plasma can provide heliumlike sodium resonance line radiated flux levels from the GAMBLE II generator to irradiate and pump the $1s^2$-$1s4p\,^1P$ line in heliumlike neon producing at least fluorescence, and possibly a modest gain.

ACKNOWLEDGMENTS

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1. J. Davis, J. E. Rogerson, and J. P. Apruzese, GAMBLE-II Imploding Sodium Plasma - I: Calibration of the Heliumlike Resonance Line as a Pump Source and Detection of Fluorescence in Neon, NRL Memorandum Report 5765, April 10, 1986.

2. F. C. Young, et.al., IEEE Plasma Science Conference, Saskatchewan, Canada, May (1986).

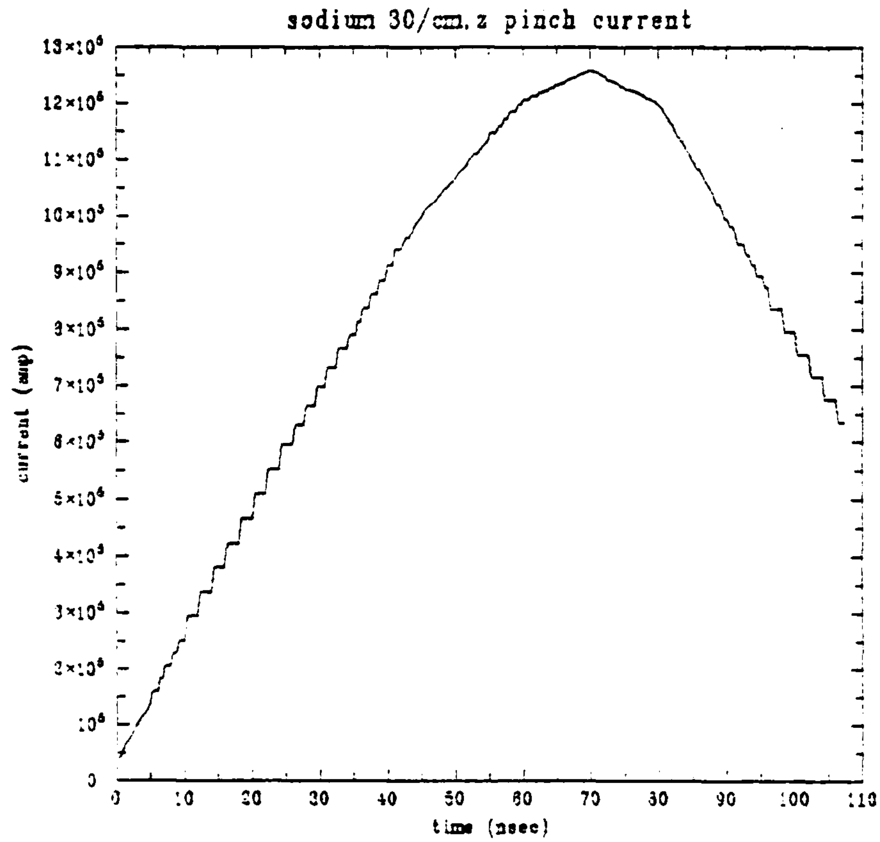

Fig. 1 GAMBLE II current as a function of time.

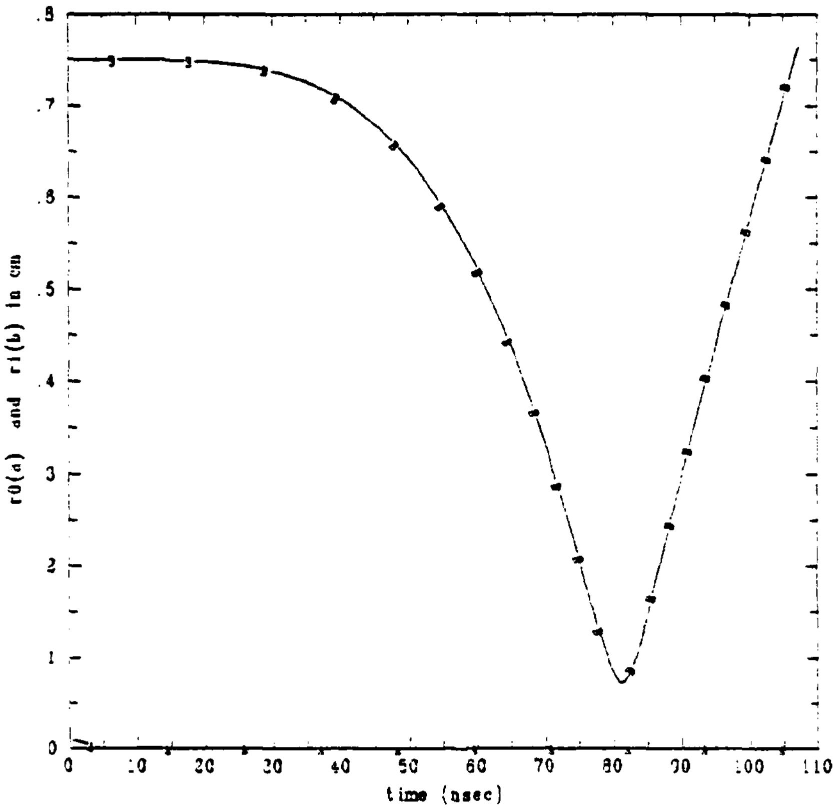

Fig. 2 Radius as a function of time.

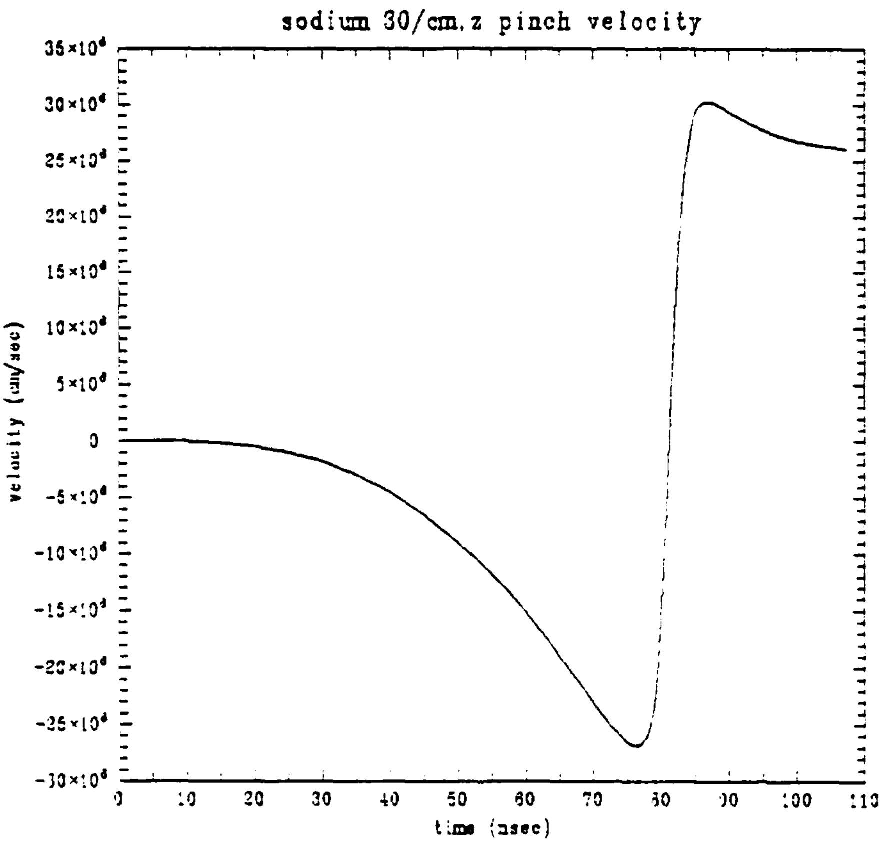

Fig. 3   Implosion velocity as a function of time.

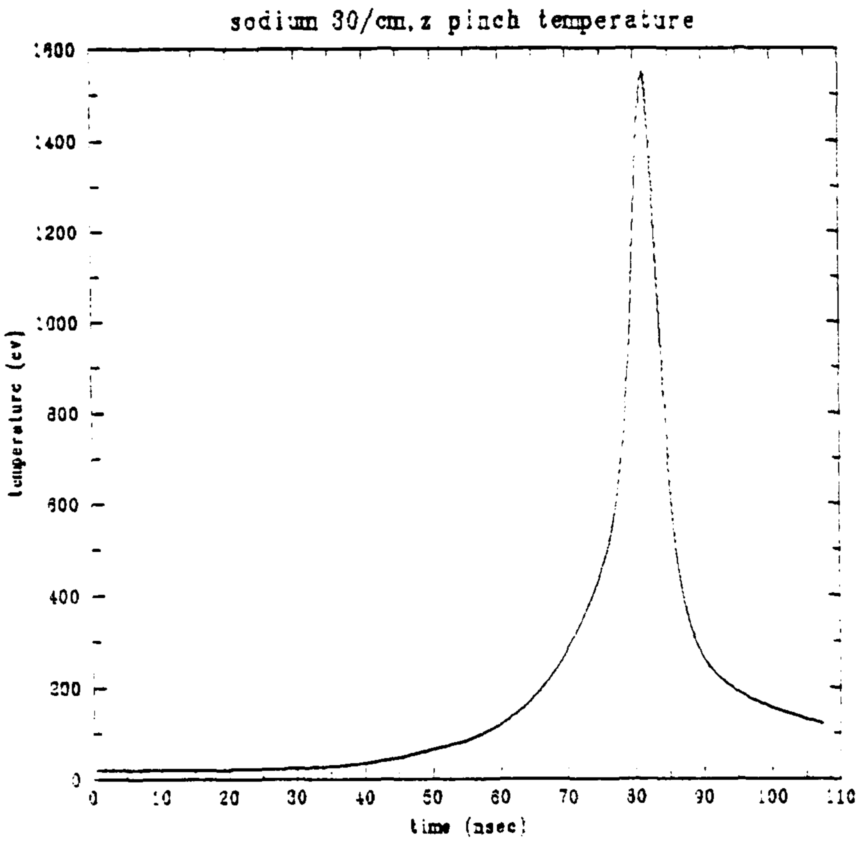

Fig. 4 Temperature as a function of time.

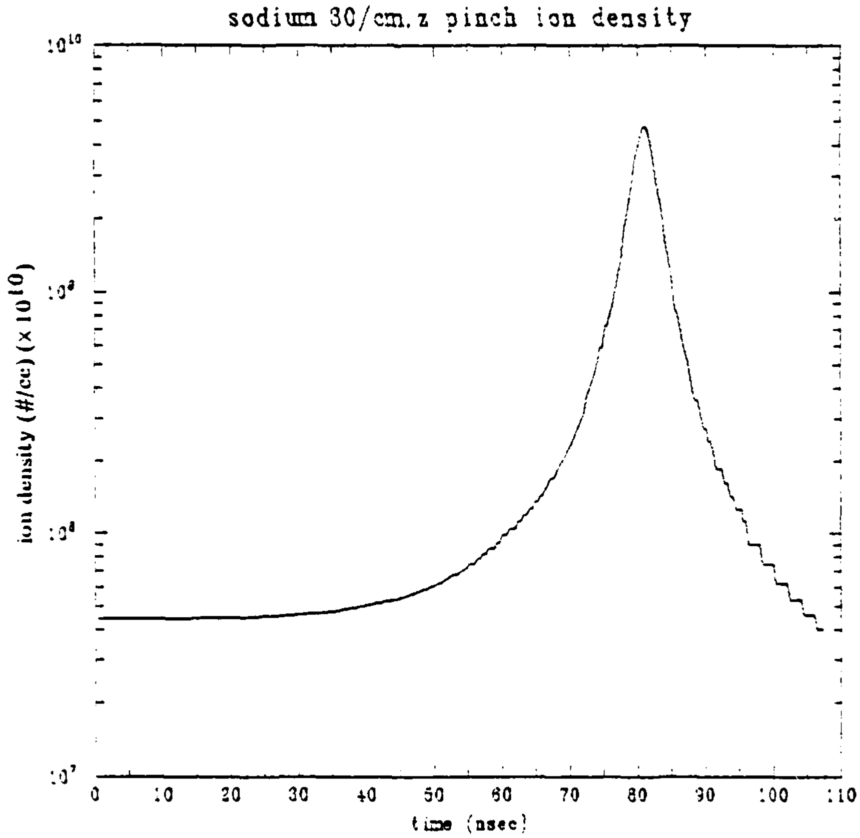

Fig. 5 Ion density as a function of time.

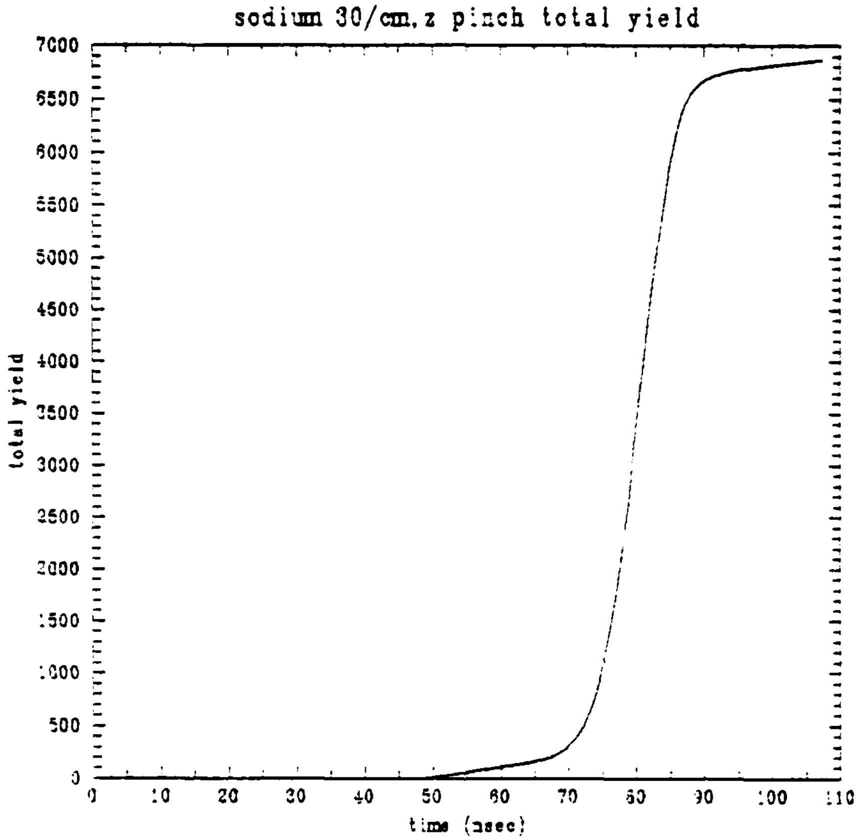

Fig. 6   Total radiative yield (Joules) as a function of time.

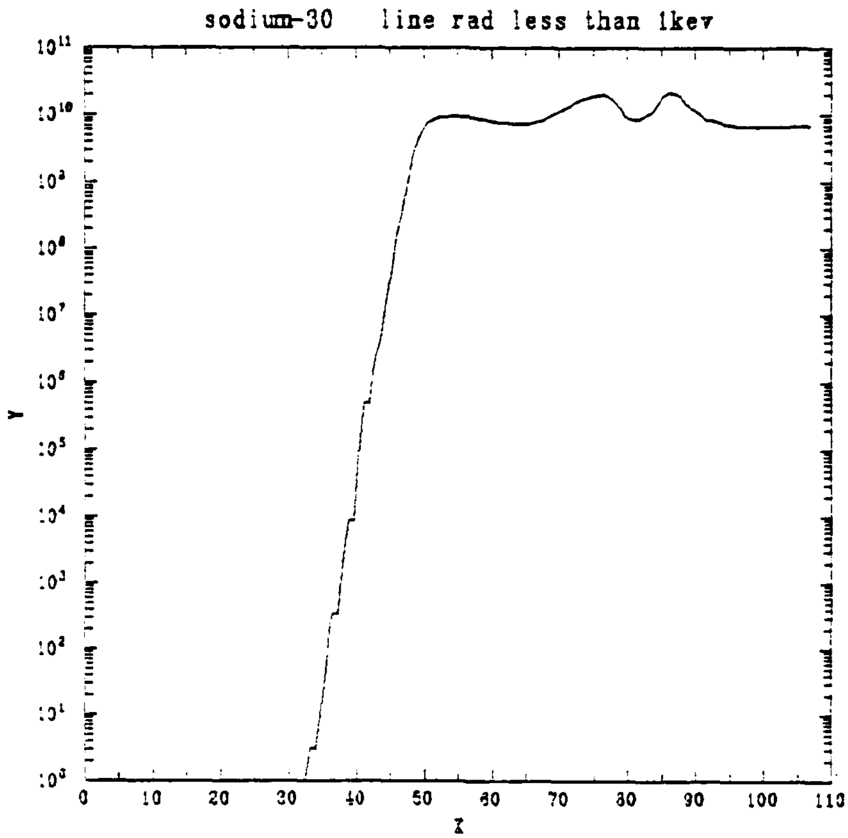

Fig. 7 Line radiation (watts) below 1 keV as a function of time.

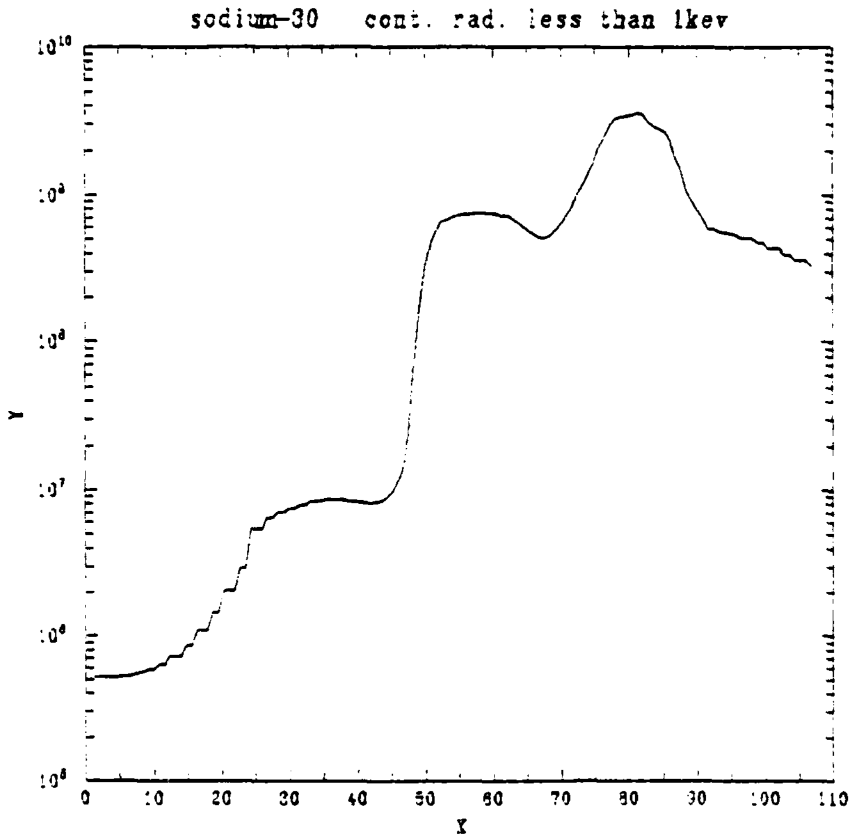

Fig. 8 Continuum radiation (watts) below 1 keV as a function of time.

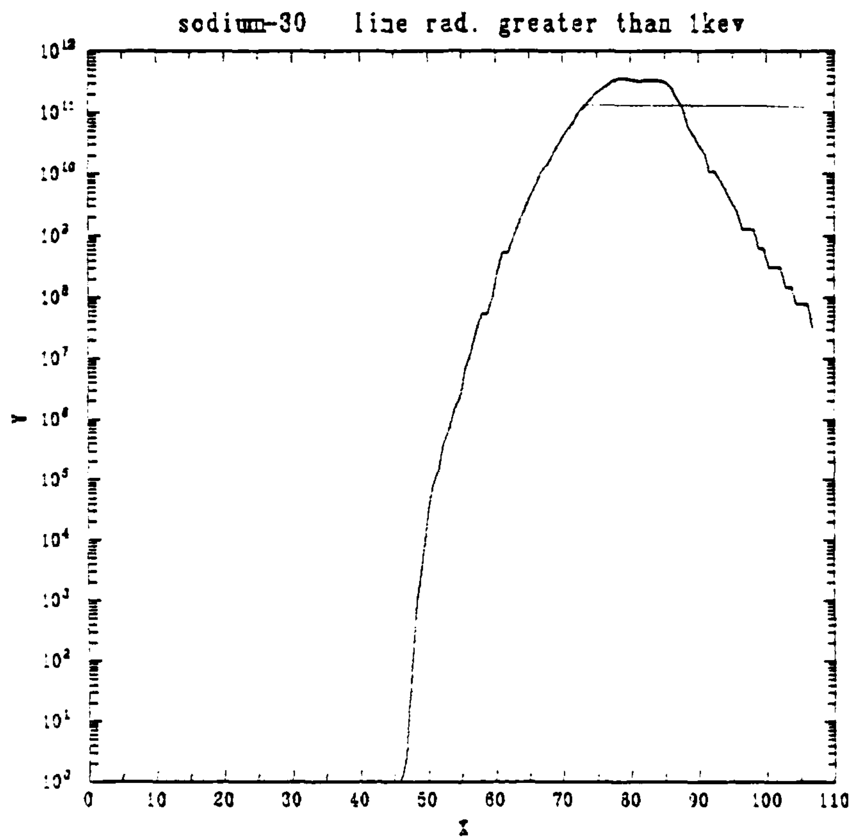

Fig. 9 Line radiation (watts) above 1 keV as a function of time.

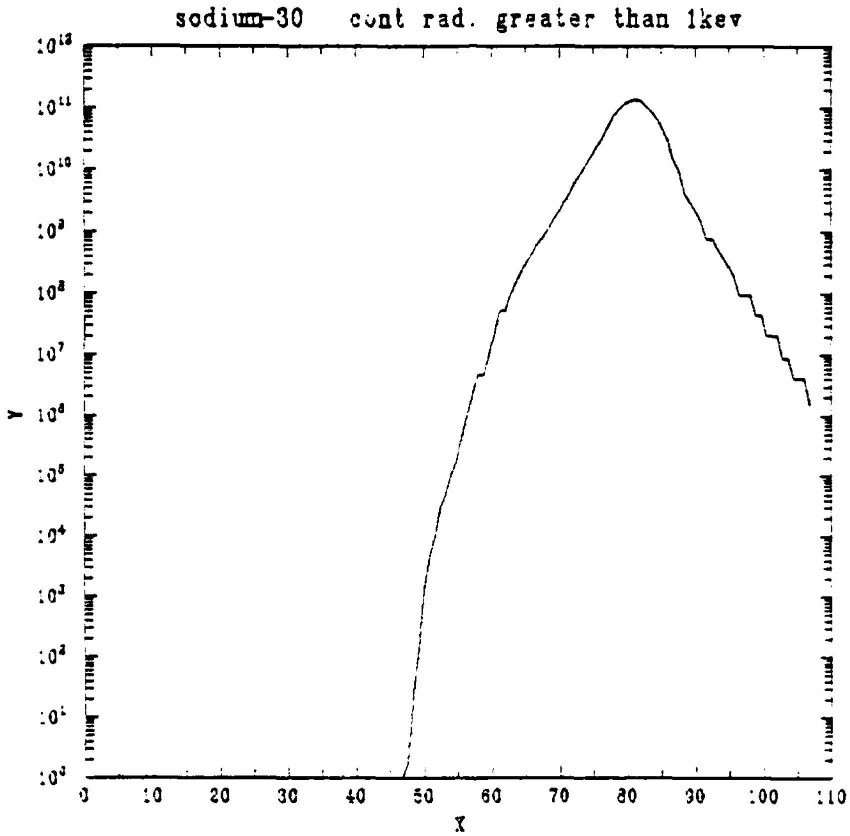

Fig. 10 Continuum radiation (watts) above 1 keV as a function of time.

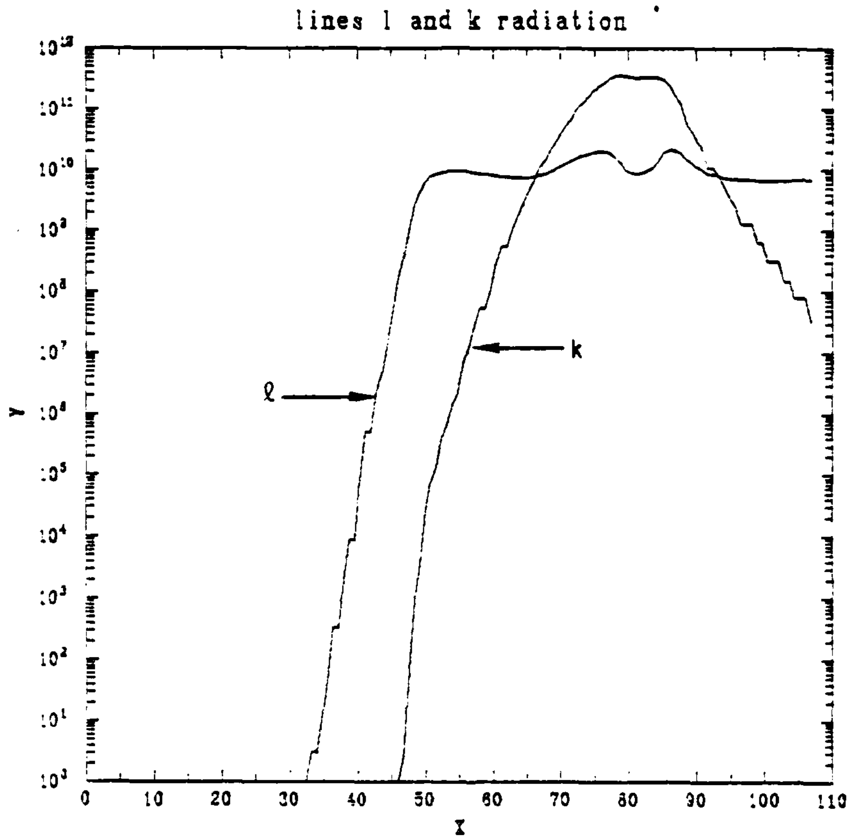

Fig. 11 L- and K-line radiation (watts) as a function of time.

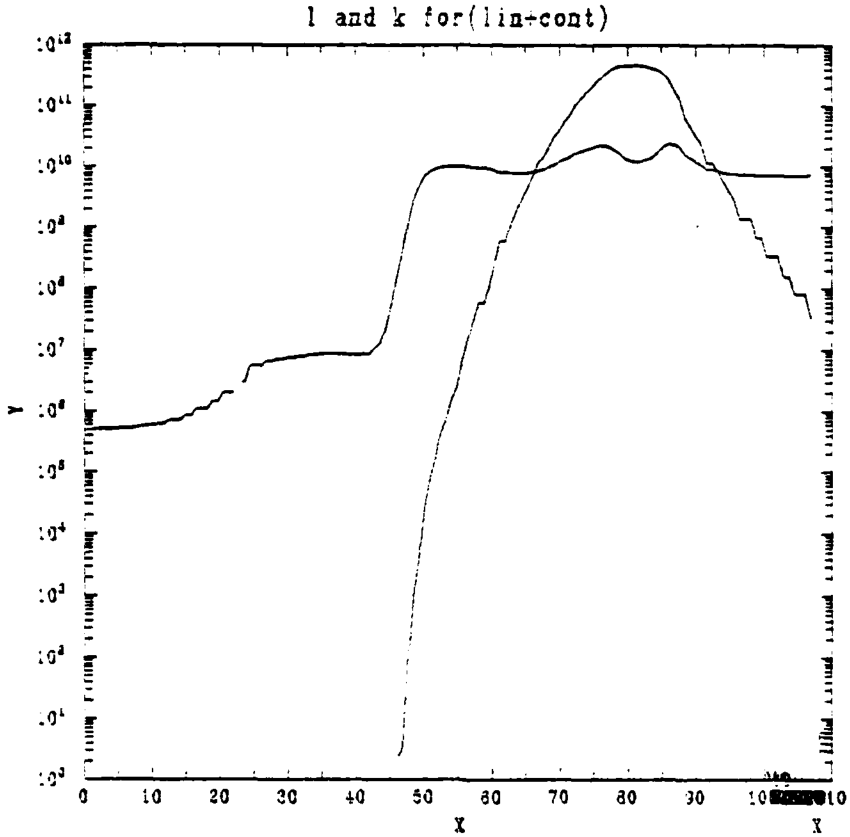

Fig. 12 L- and K-line and continuum radiation (watts) as a function of time.

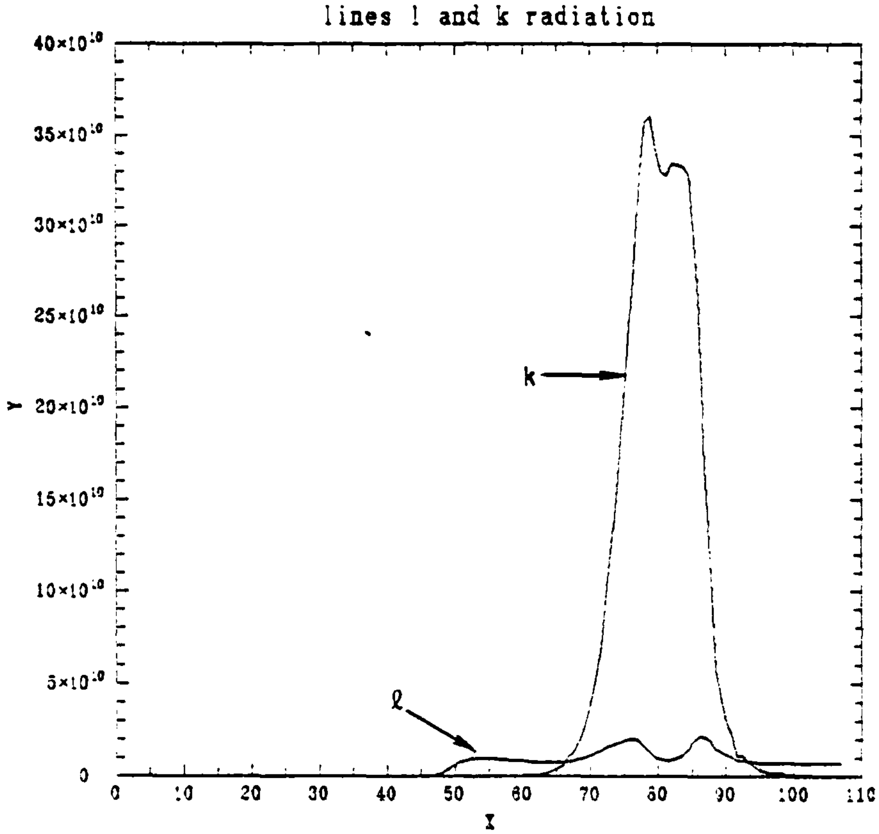

Fig. 13 L- and K-line radiation (watts) as a function of time.

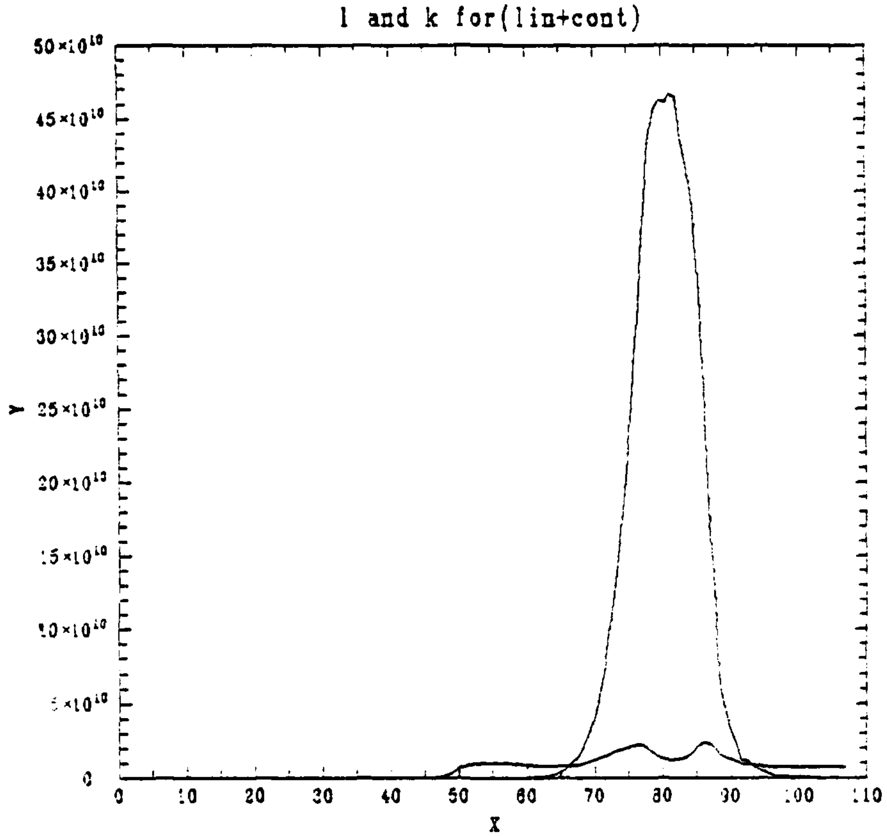

Fig. 14 L- and K-line and continuum radiation (watts) as a function of time.

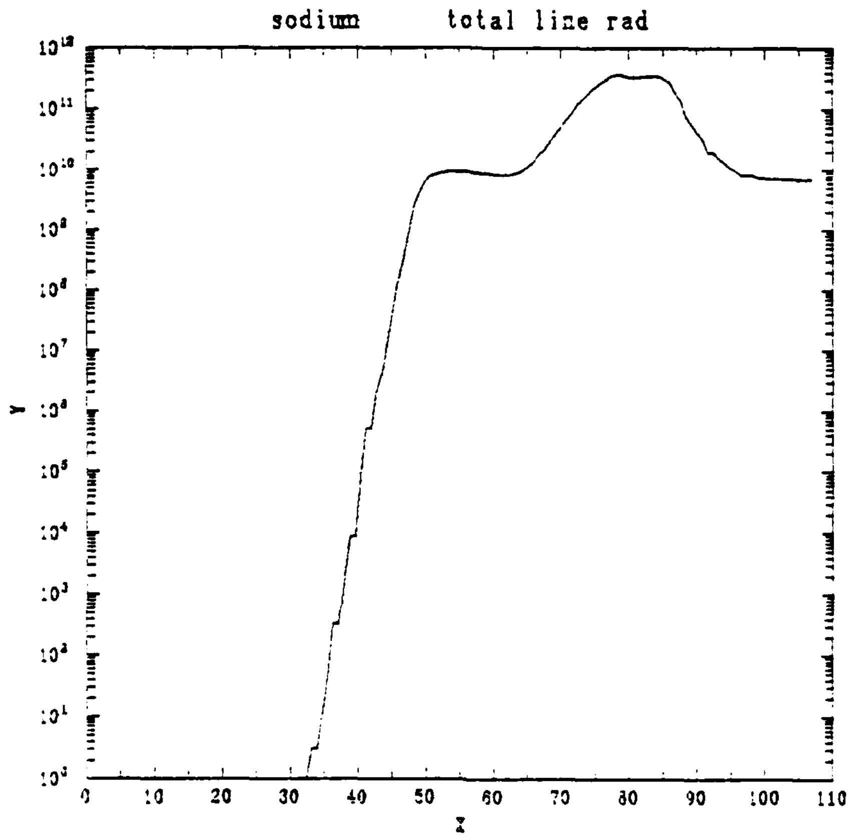

Fig. 15 Total line radiation (watts) as a function of time.

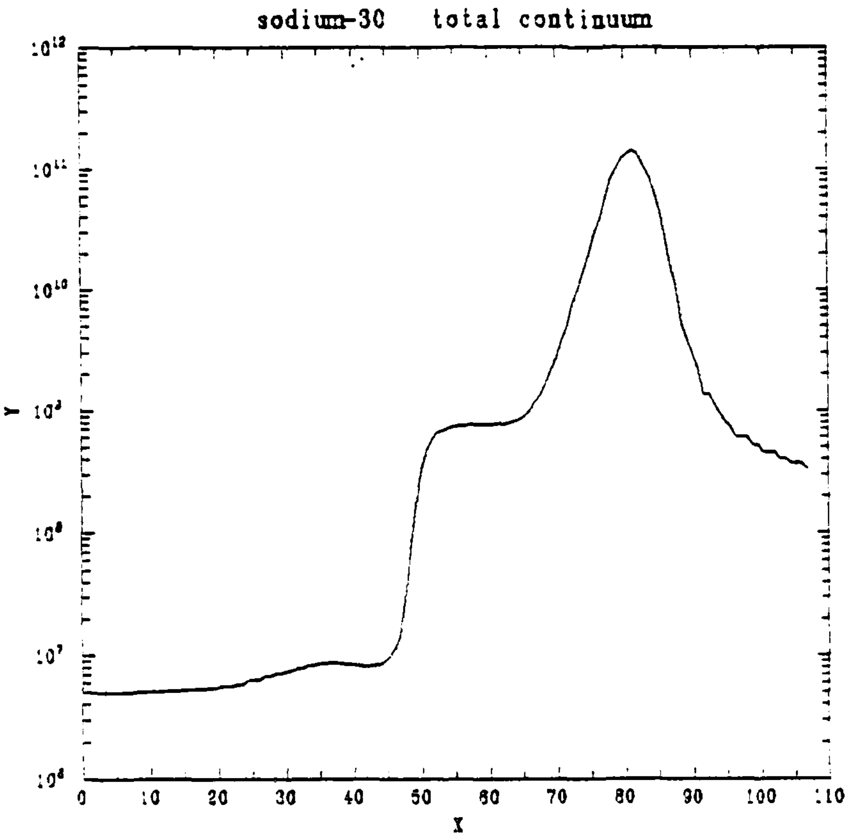

Fig. 16 Total continuum radiation (watts) as a function of time.

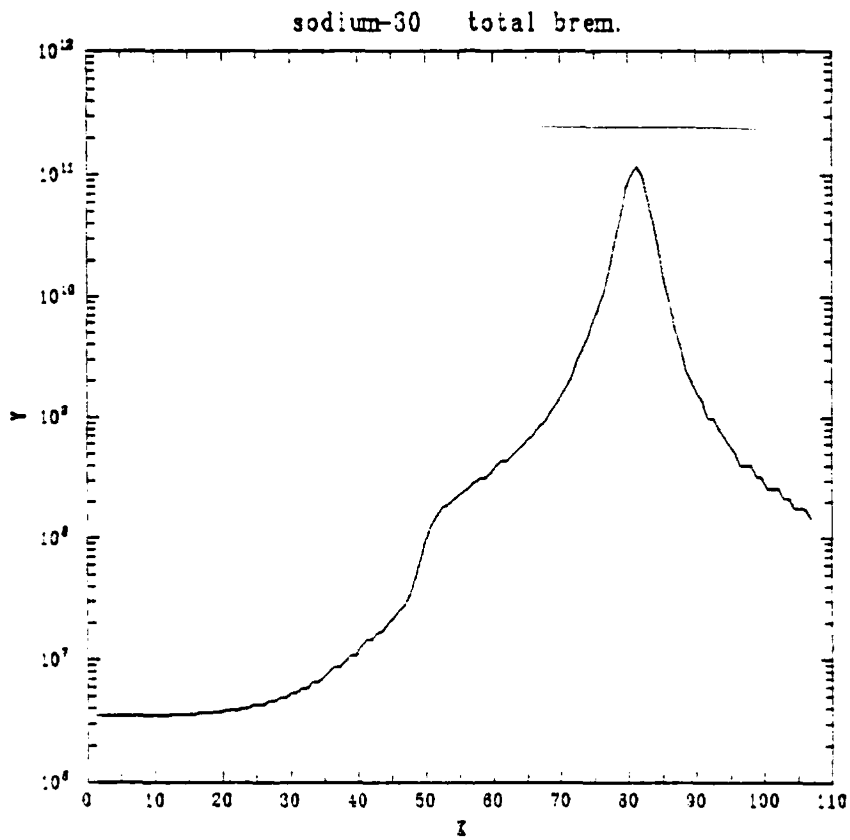

Fig. 17 Total bremsstrahlung radiation (watts) as a function of time.

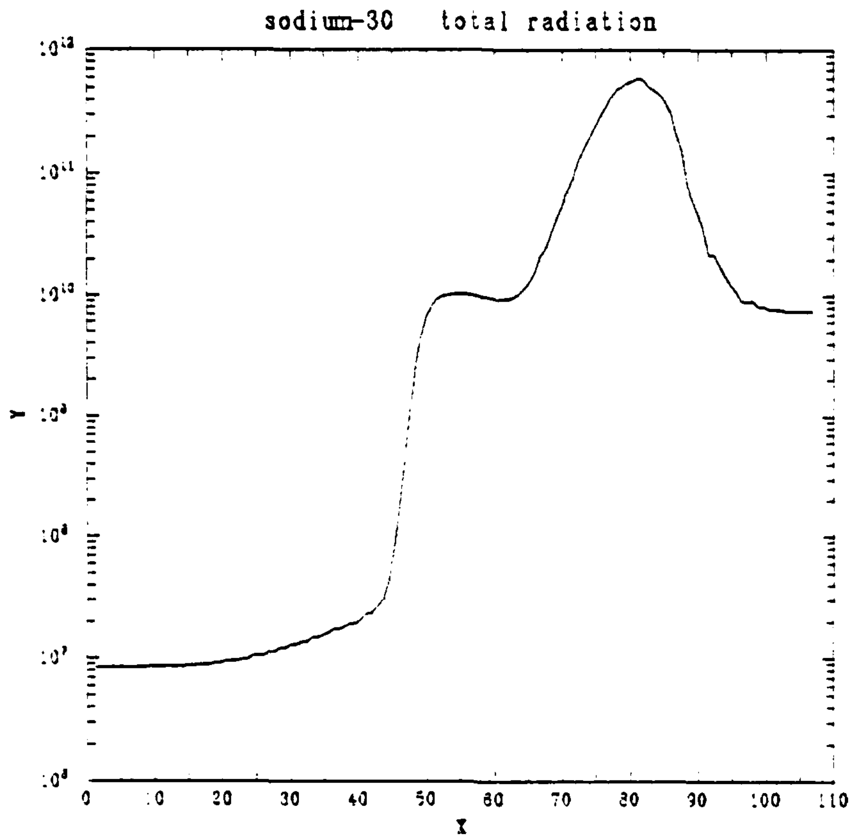

Fig. 18 Total radiation (watts) as a function of time.

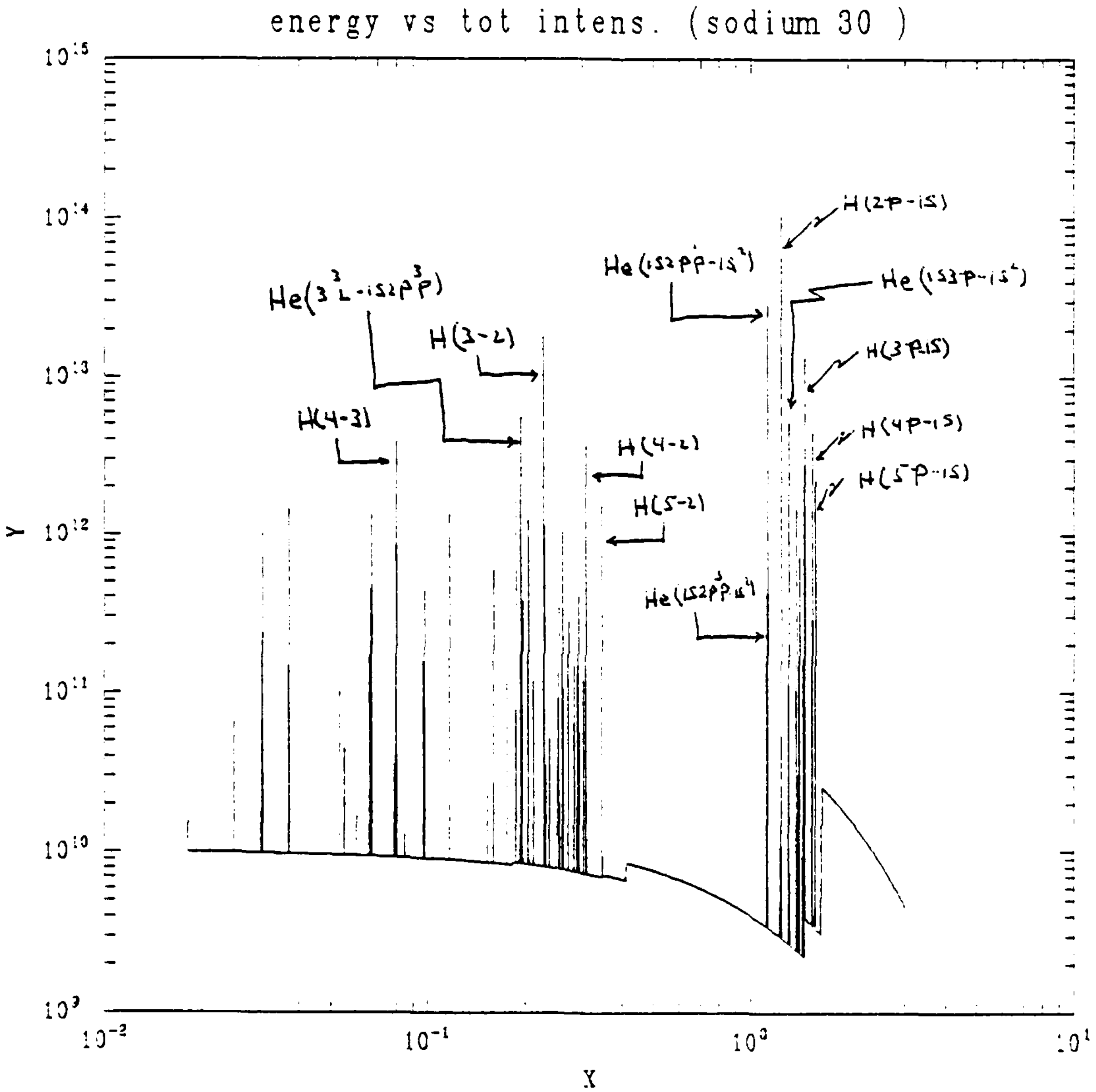

Fig. 19 Emission spectra (watts/cm^2) as a function of energy (keV) at 84.2 nsec.

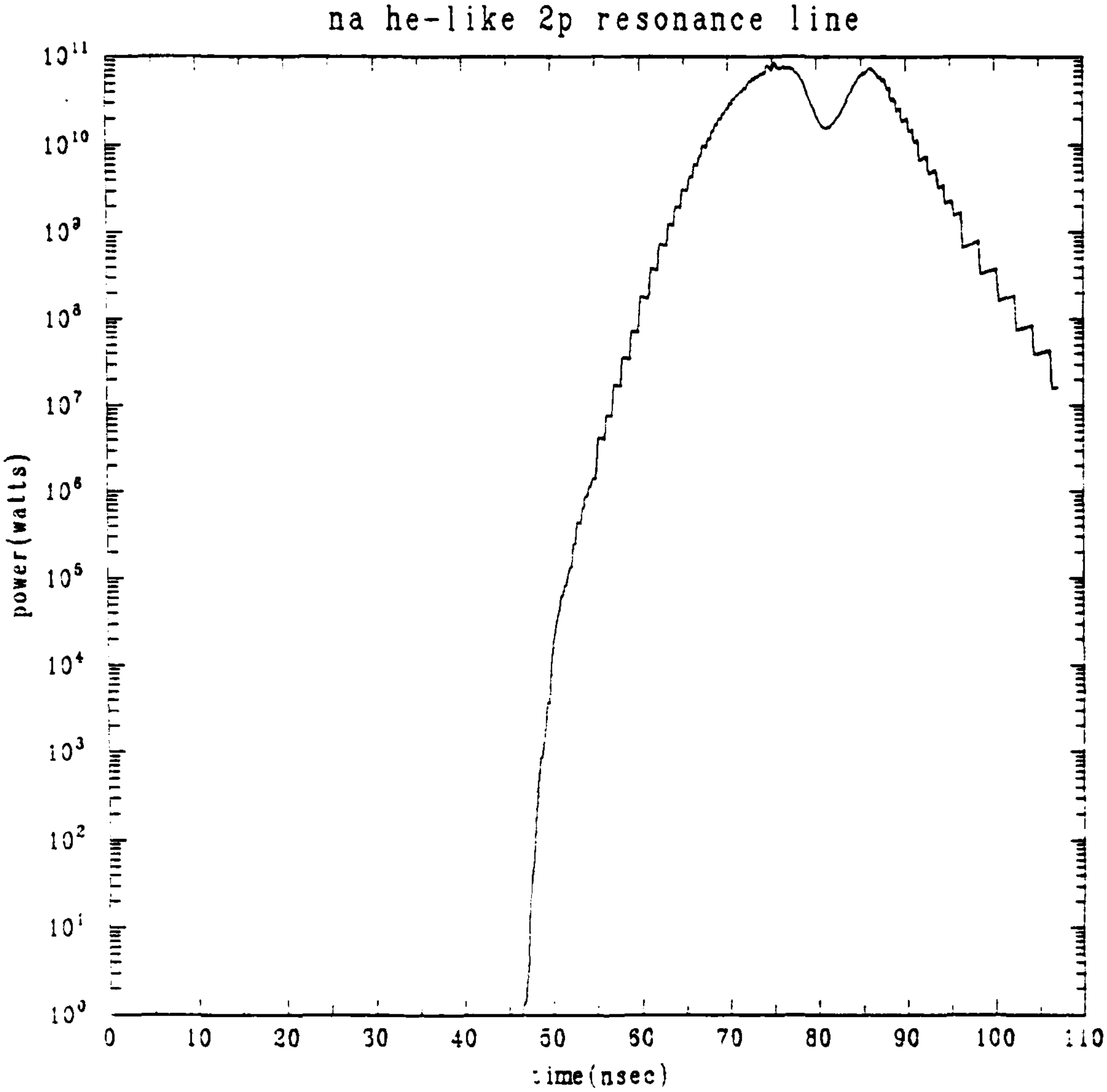

Fig. 20 Radiation from heliumlike resonance line (watts) as a function of time.

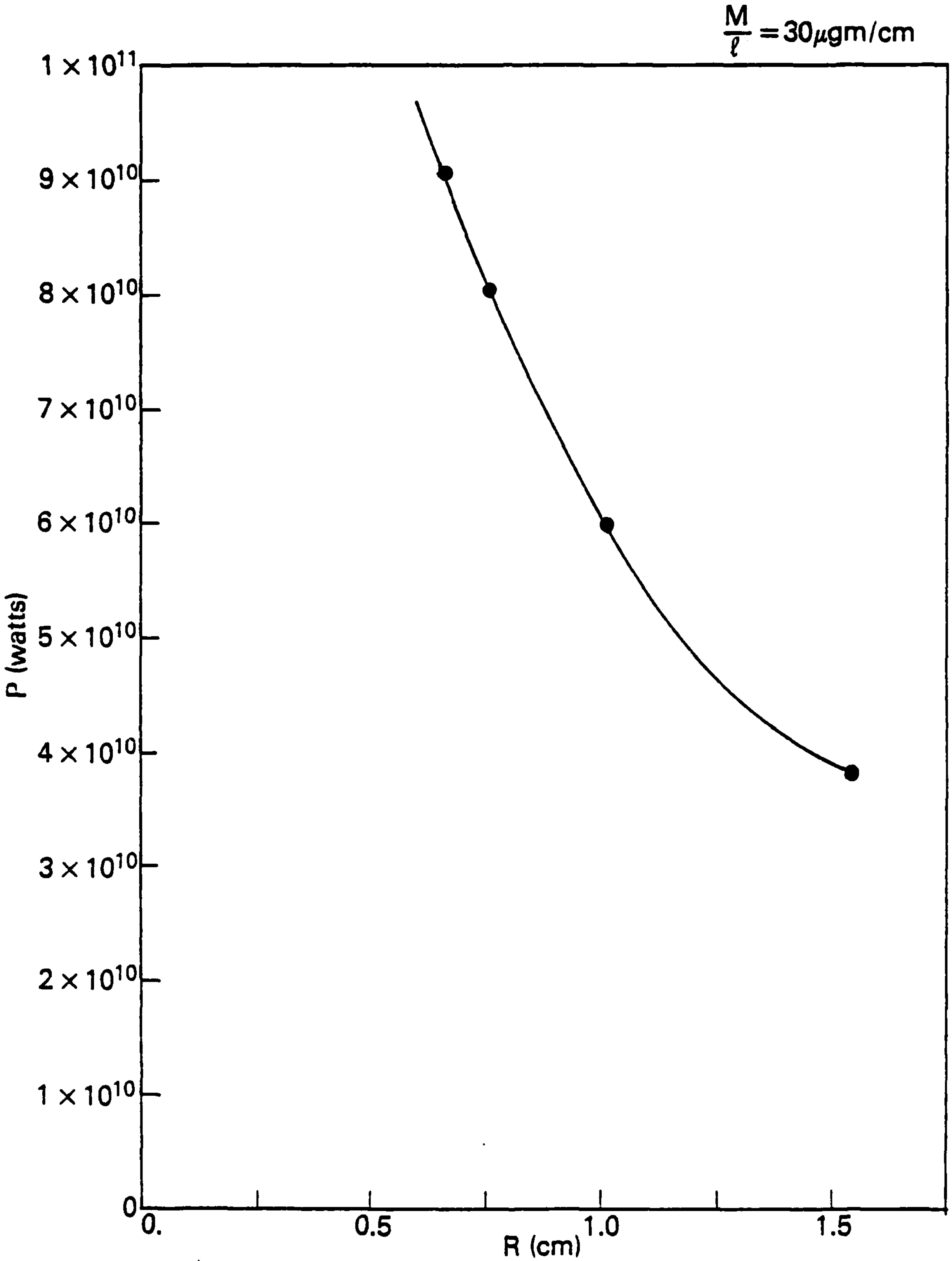

Fig. 21 Radiation from heliumlike resonance line (watts) as a function of initial radius of the discharge.

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